



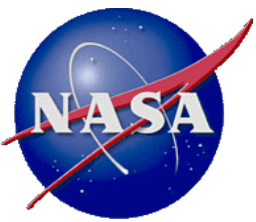
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Certification of Electronics with Heavy Ions for Deep Space

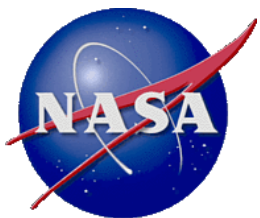
**Radiation Technologies Event at JSC
September 21, 2016**

**Brandon Reddell, PhD
NASA Johnson Space Center
Engineering Directorate
brandon.d.reddell@nasa.gov
281-483-5050**

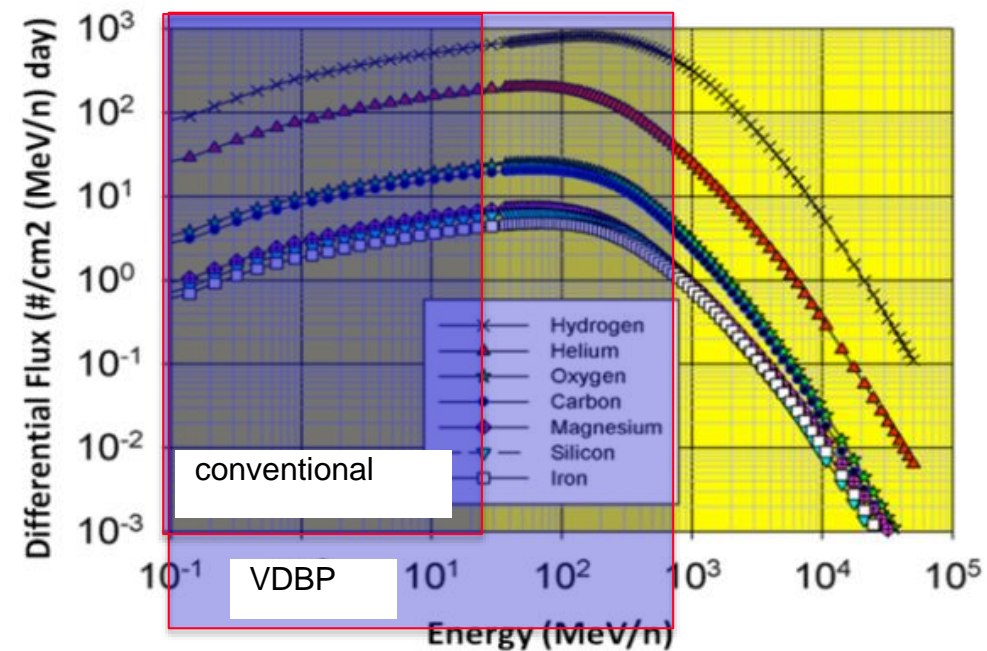


Outline

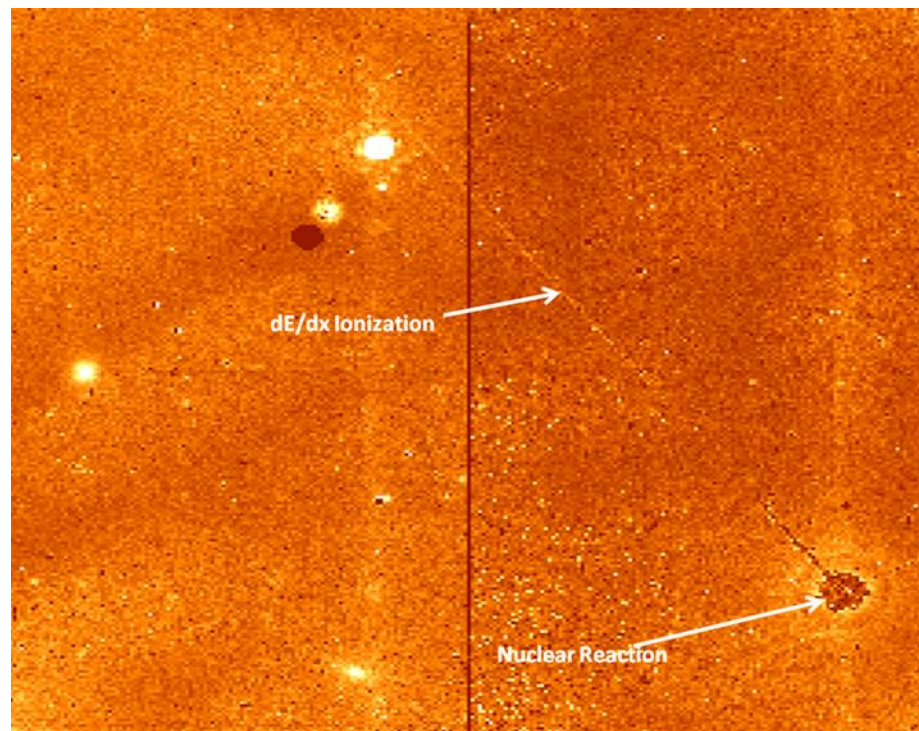
1. Purpose of Radiation Testing
2. Why a New Test Method?
3. Variable Depth Bragg Peak – Method
4. VDBP Validation & Results
5. VDBP Forward Work

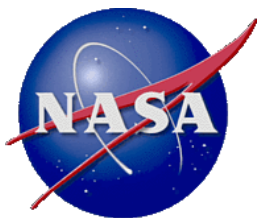


Galactic Cosmic Radiation (GCR)



GCR inside material

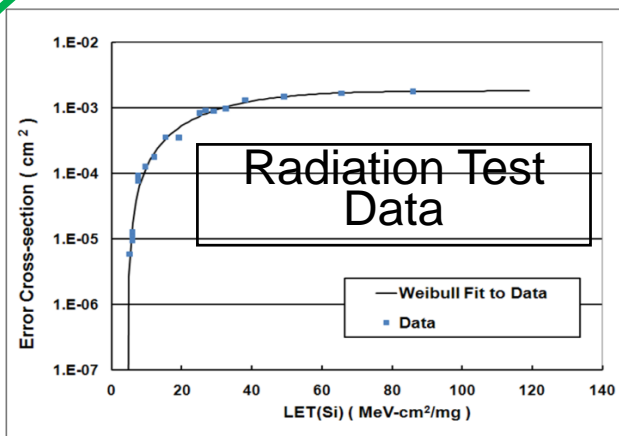
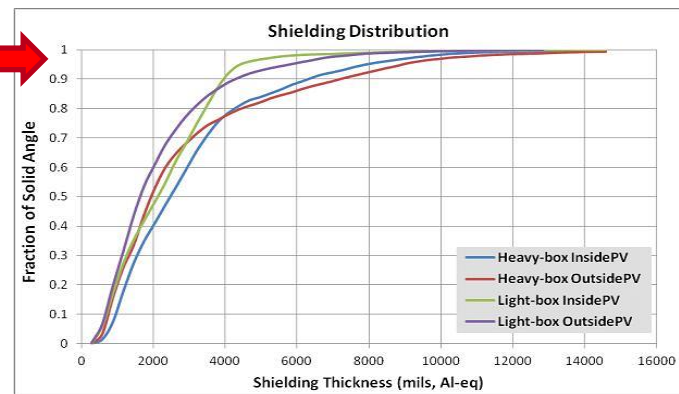
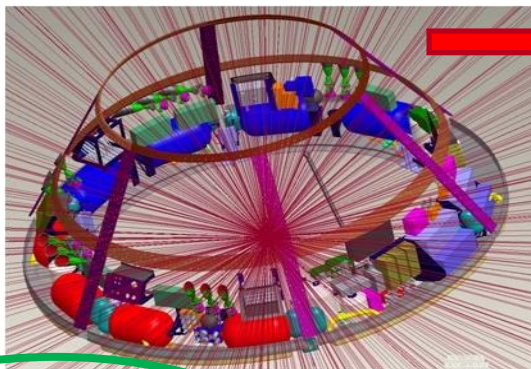
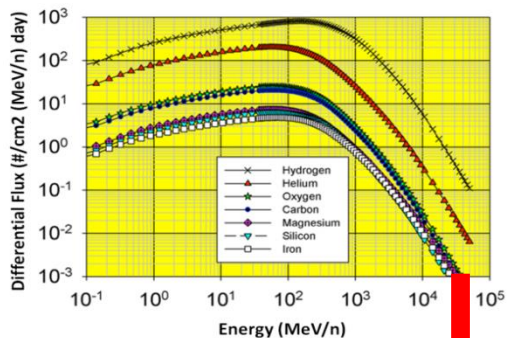




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Process for Ionizing Radiation Analysis of Electronic Parts



This is what we are after!

Part Failure Rate

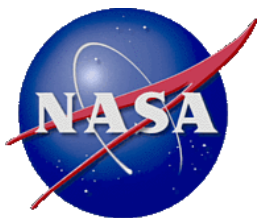
Reliability Analysis



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Why a new test method?



U.S. Radiation Facilities

Testing Facility	Beam Type	Cost
Indiana University Cyclotron Facility (IUCF)	High Energy Proton	\$675/hour * Not available starting 2015
Brookhaven Tandem Van de Graff Generator (TVDG)	Low Energy Heavy Ion	\$1250/hour
Texas A&M University Cyclotron Facility (TAMU)	Low Energy Heavy Ion	\$900/hour
Lawrence Berkeley National Laboratory - University of California at Berkley (LBNL)	Low Energy Heavy Ion	\$1300/hour
NASA Space Radiation Laboratory (NSRL)	High Energy Heavy Ion	\$5500/hour



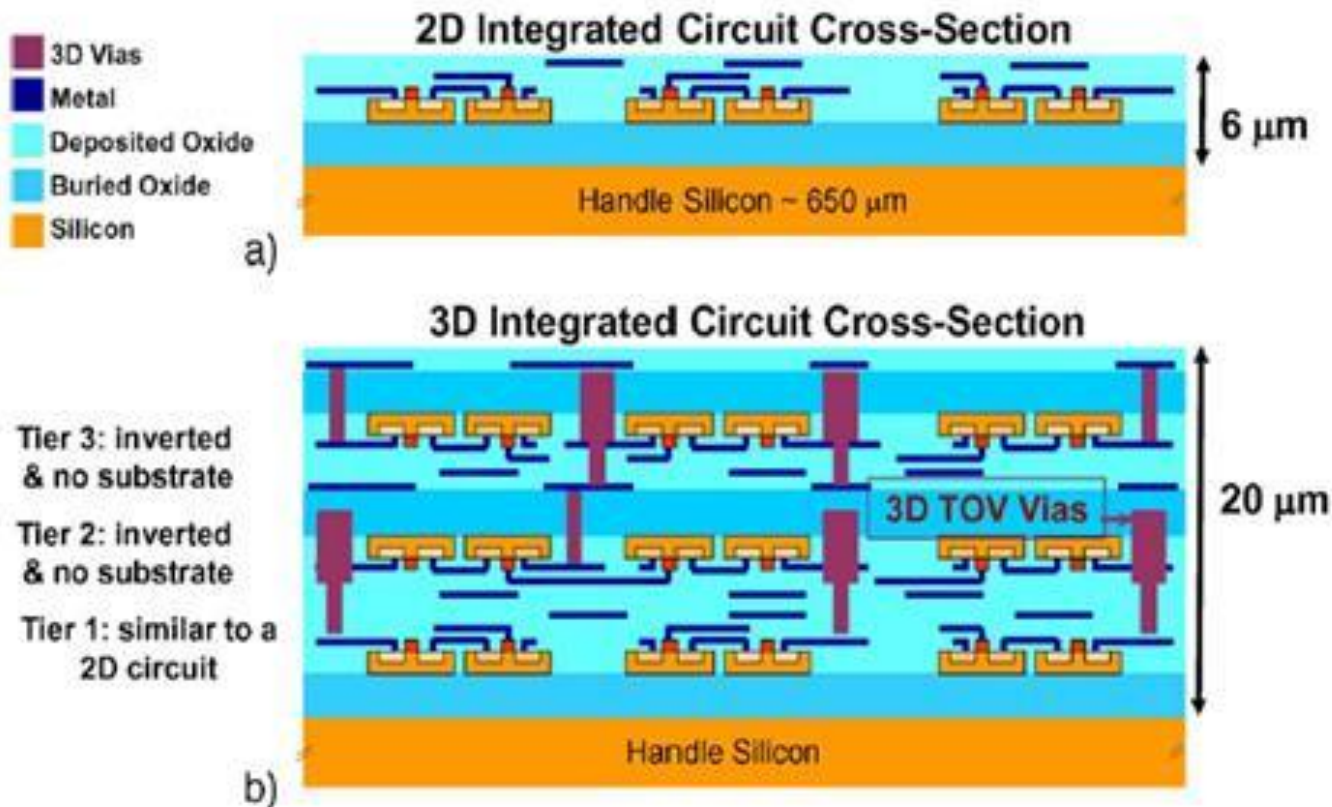
Concerns for Traditional Radiation Testing of Electronic Parts for Deep Space

- **High Energy Protons (≥ 200 MeV)**
 - can only test to LET < 15 MeV/mg/cm²
 - can not be used to certify hardware for deep space
 - **Low Energy Heavy Ions ($0 < \text{LET} < 100$ MeV/mg/cm²)**
 - requires that parts have to have packaging removed (de-lidding)
 - * Extra parts required for purchase (~50% survive de-lidding process)
 - De-lidding/test board setup process may impact schedule
 - Limited ability to test circuit/system (only piece-part)
 - Typically takes ~8 hours/part-type to characterize (at ~\$1100/hr)
 - Trends in part technology preclude the use of low energy heavy ions
- **Costly! NASA/MPCV/Orion spent ~\$1.2 million between 2011 and 2012**
(beam time only - does not include any of the sub-contractor costs or associated labor hours)

*depends on packaging style

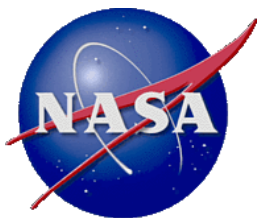


New Technologies & Commercial Parts



Can the packaging be removed? Is this a flip-chip technology?

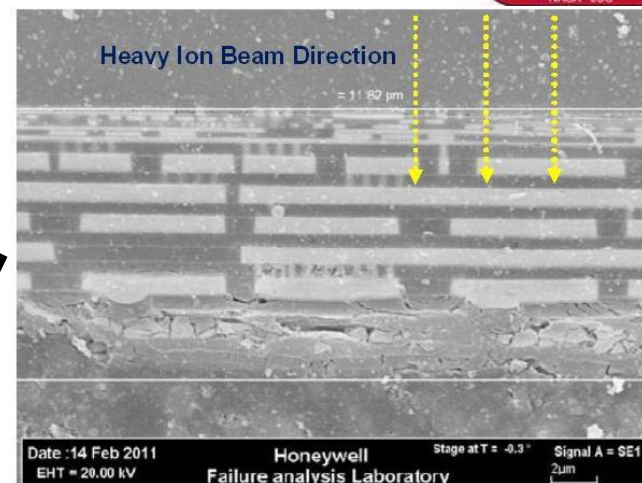
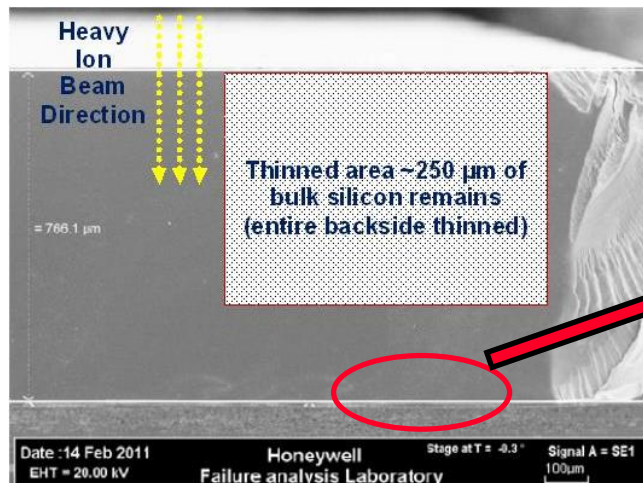
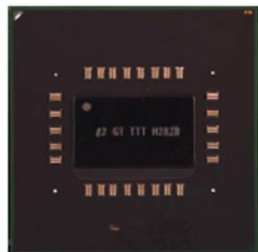
How do we test these technologies at low energy facilities?



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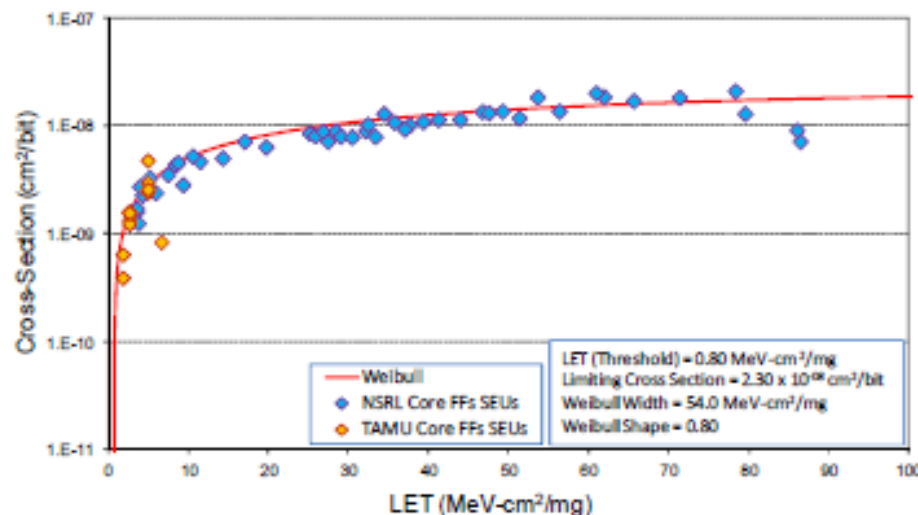


Modern Parts Example: Altera Hardcopy IV ASIC



ASIC 40 nm technology – high priority part for Orion Flight Computer

- Expensive part (several \$100k)
- For Orion Lunar mission, need to qualify part to LET ≥ 75 MeV-cm²/mg
- Attempted to remove ~750 microns of Si, but couldn't without damaging part
- At conventional heavy ion facility (TAMU), max LET achievable was 18 MeV-cm²/mg
- Part successfully characterized using VDBP at NSRL

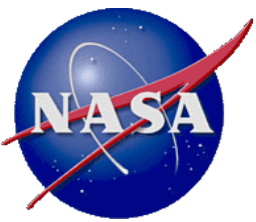




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Variable Depth Bragg Peak (VDBP) Method



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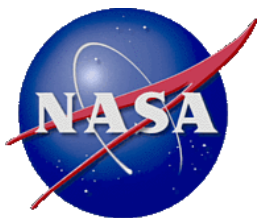
Brookhaven National Laboratory



NASA
Space
Radiation
Laboratory
(NSRL)



- 1) Tandem (2-20 MeV/n) or EBIS/LINAC (200 MeV)
- 2) **Booster: 20 MeV/n – 2 GeV/n (NSRL gets beam from here)**
- 3) AGS: 2 GeV/n – 28 GeV/n
- 4) RHIC: 20 GeV/n – 200 GeV/n



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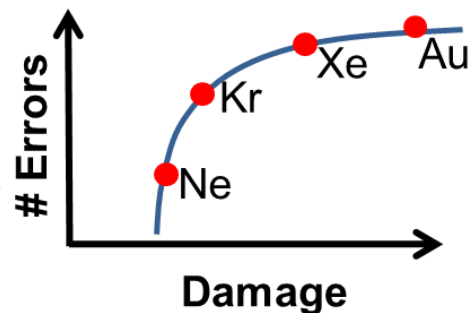
Traditional Test

Provides ions with specific damage level

Cyclotron

radiation

Delidded Electronic Part



In the medical industry, cancer therapy is used to focus ionizing radiation beams on tumors. They place the Bragg Peak on the tumor which deposits energy in the tumor thus destroying it.



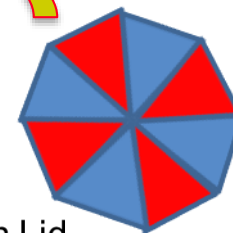
Sensitive Volume

Energy deposited (damage) in the sensitive volume causes errors. more damage = more errors/failure

Degrader Wheel Placed Here



Applied to electronics...

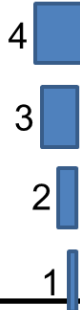


VDBP Test

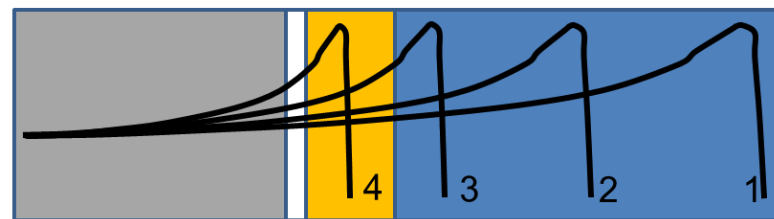
(C. Foster, P. O'Neill
- NASA JSC)

Beam

Degrader Steps



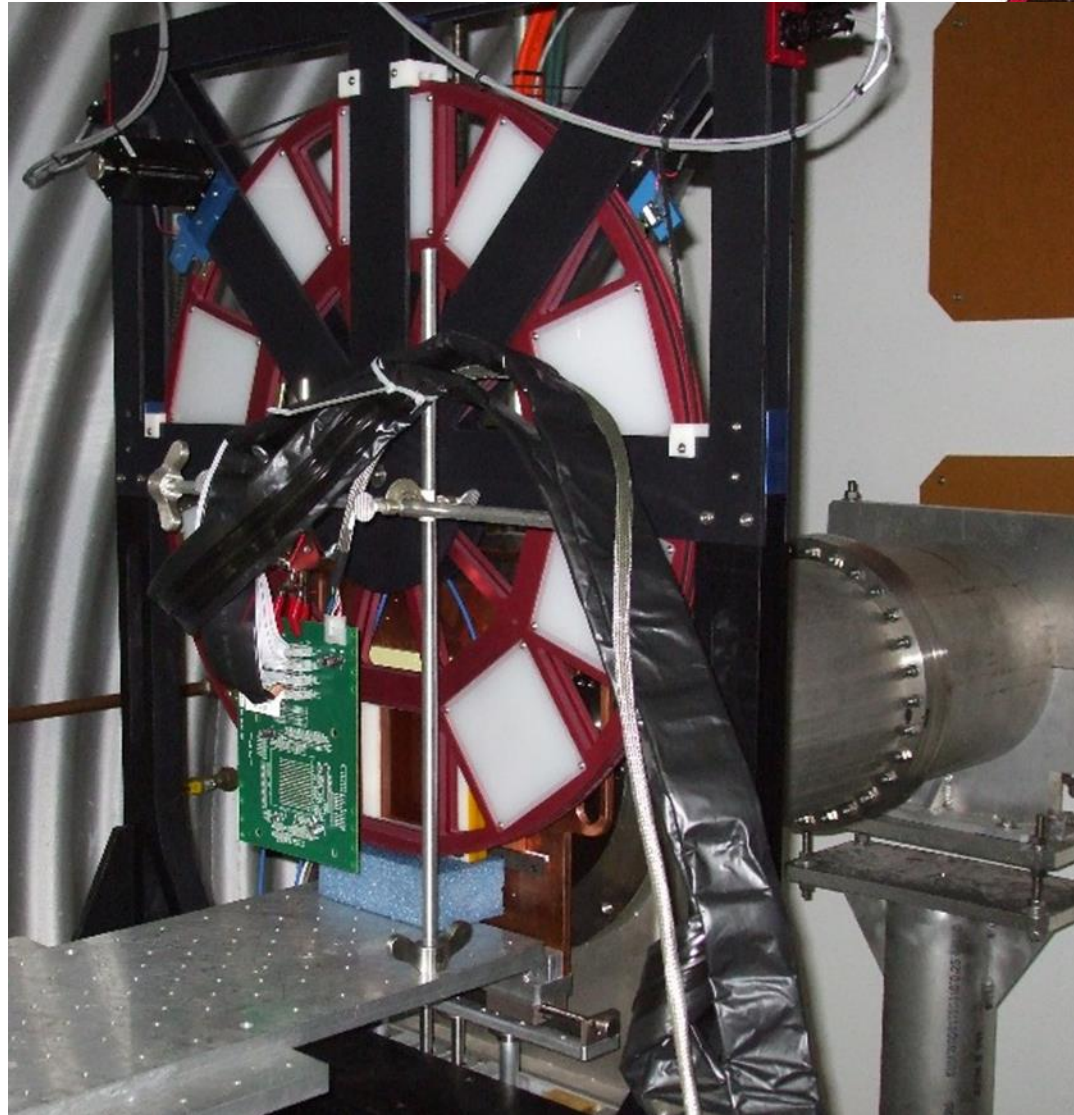
Electronic Part with Lid

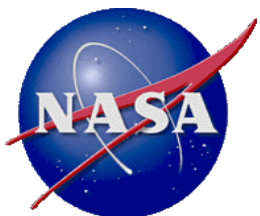




Degrader System at NSRL

NASA Space Radiation
Laboratory at
Brookhaven spent ~\$50k
to develop degrader
system for VDBP

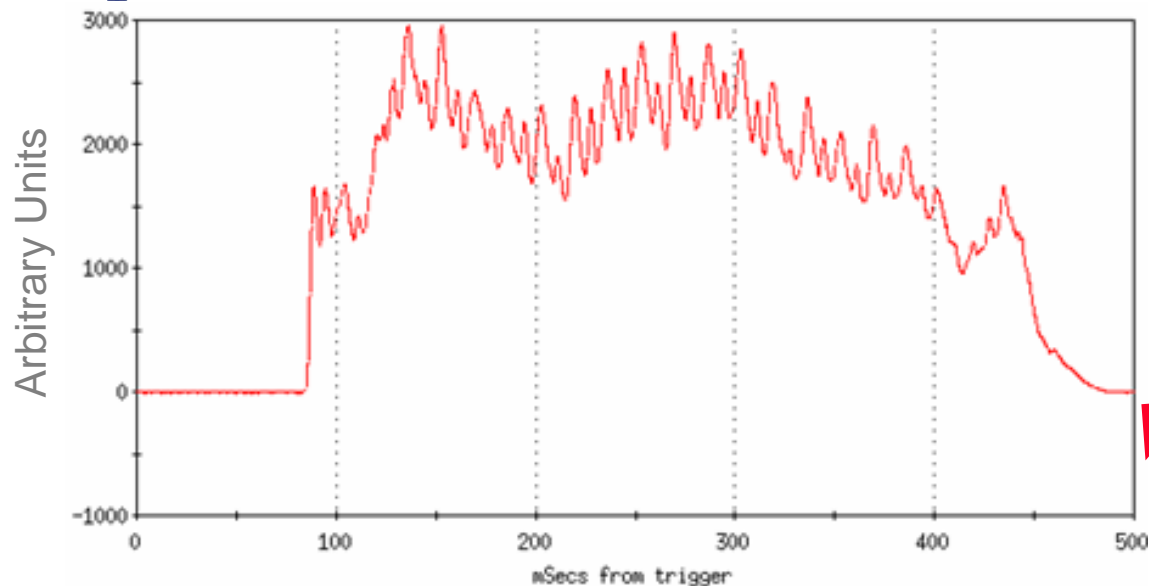




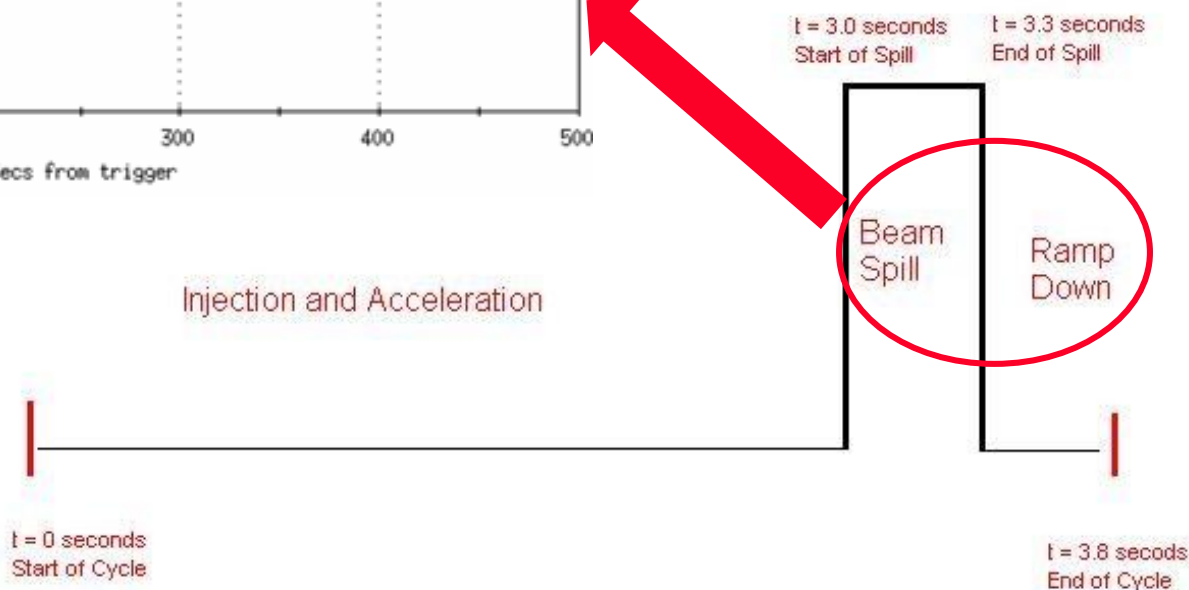
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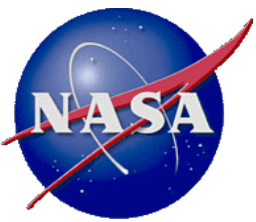
NSRL Spill/Intensity vs. Time



There is a concern for certain error modes that this beam profile will impact testing: This has not been observed to date.

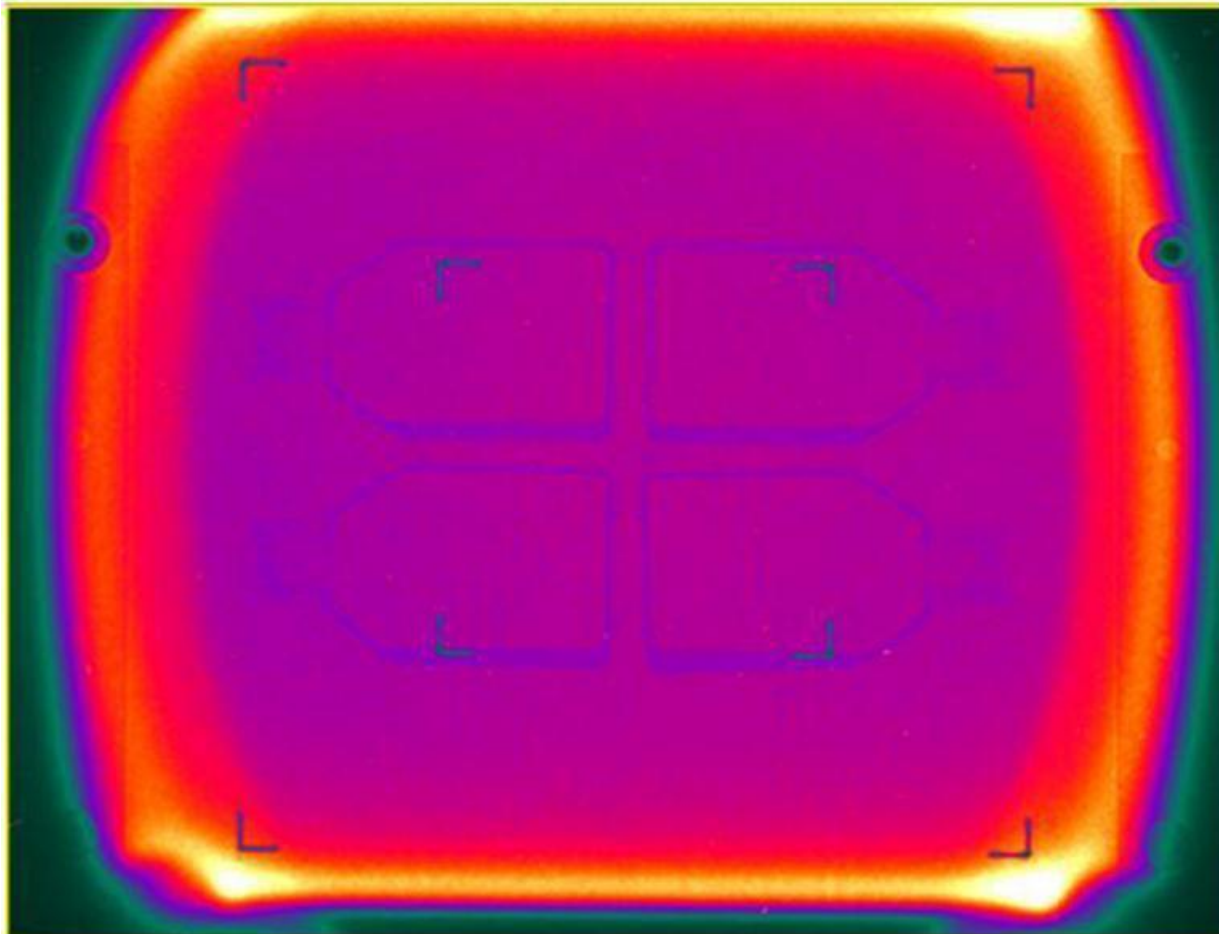


- Nominally a 0.4 sec spill every 4 seconds

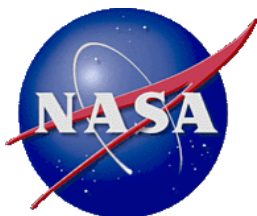


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NSRL 20cm x 20cm Beam Intensity



- $\sim 100 < \text{Flux} < 1e6$ (or higher) particles/cm²/spill (spill every 4-5 seconds)
 - Beam spot as low as $\sim 1\text{in} \times 1\text{in}$ for piece part testing
-
- Large beam spot can be used for system level testing



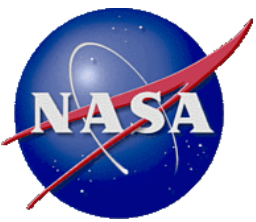
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NSRL Available Beams



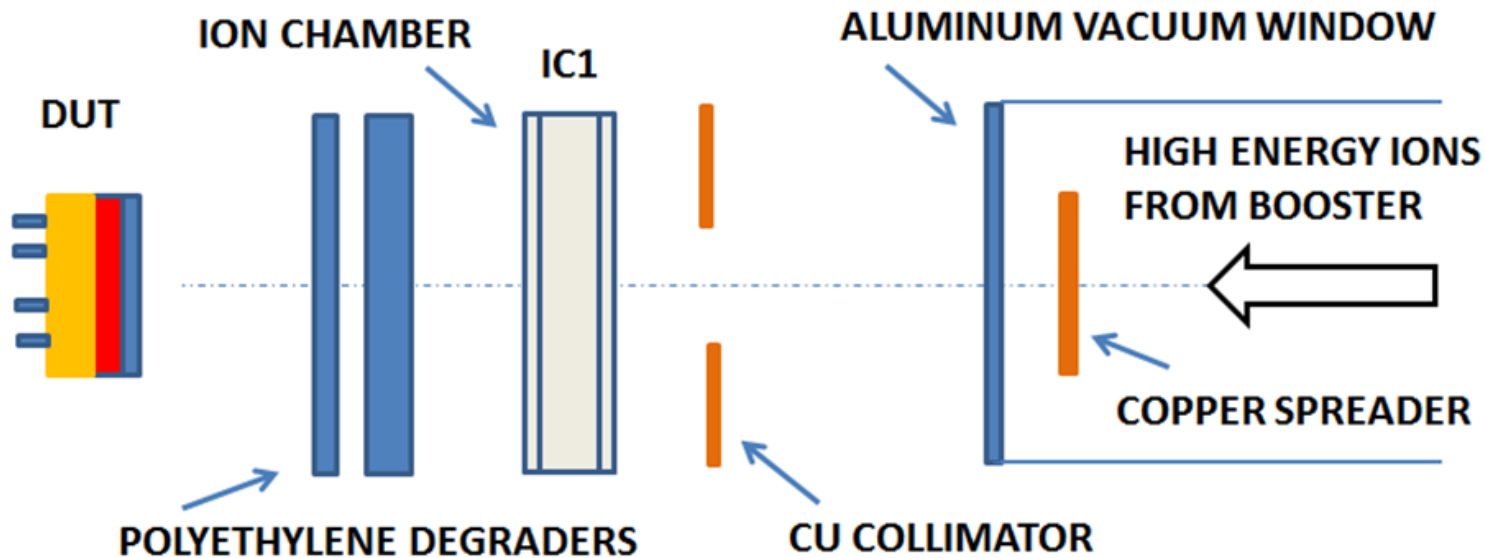
Electronics Testing

Ion Species [1]	Max Energy [2] (MeV/n)	LET in silicon at Max Energy [6] (MeV/(mg/cm ²))	Peak LET in silicon (MeV/(mg/cm ²))	Range in silicon (millimeters)	Max Flux [3] (ions/spill)
${}^1_1\text{H}^1$	2500	0.00171	0.530	5470	2.2×10^{11}
${}^3_2\text{He}^3$	1000	0.0069	1.45	1910	0.88×10^{10}
${}^4_2\text{He}^4$	1000	0.0072	1.5	1705	0.88×10^{10}
${}^{12}_6\text{C}^{12}$	1000	0.066	5.4	568	1.2×10^{10}
${}^{16}_8\text{O}^{16}$	1000	0.117	7.44	426	0.4×10^{10}
${}^{20}_{10}\text{Ne}^{20}$	1000	0.183	9.77	341	1.2×10^{10}
${}^{28}_{14}\text{Si}^{28}$	1000	0.358	14.5	243	0.3×10^{10}
${}^{35}_{17}\text{Cl}^{35}$	1000	0.528	18.1	206	0.2×10^{10}
${}^{40}_{18}\text{Ar}^{40}$	350	0.857	19.27	43.3	0.02×10^{10}
${}^{48}_{22}\text{Ti}^{48}$	1000	0.884	24.0	169	0.08×10^{10}
${}^{56}_{26}\text{Fe}^{56}$	1000	1.235	28.6	141	0.2×10^{10}
${}^{84}_{36}\text{Kr}^{84}$	383	3.28	40.1	26.5	2.0×10^7
${}^{132}_{54}\text{Xe}^{132}$	228	9.75	61.1	8.23	5.0×10^7
${}^{181}_{73}\text{Ta}^{181}$	342	14.8	83.3	10.6	3.0×10^8
${}^{197}_{79}\text{Au}^{197}$	165	24.7	90.2	3.70	1.0×10^8



VDBP Model

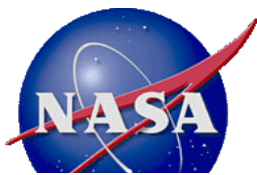
Exposure Set Up



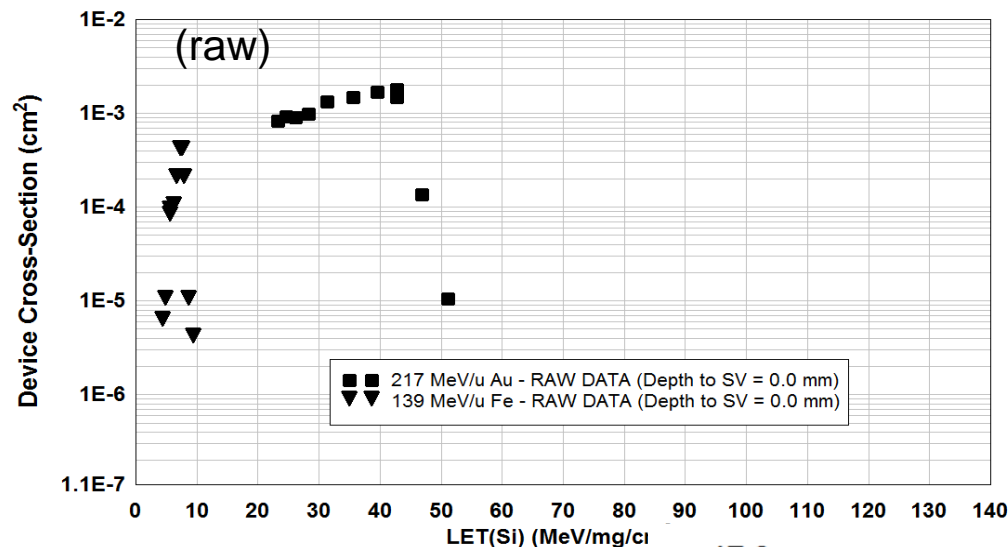
Known: Ion Species (Gold, Iron, Carbon, etc.)

Energy of Ions from Booster Synchrotron, $E_B \pm \Delta E_B$

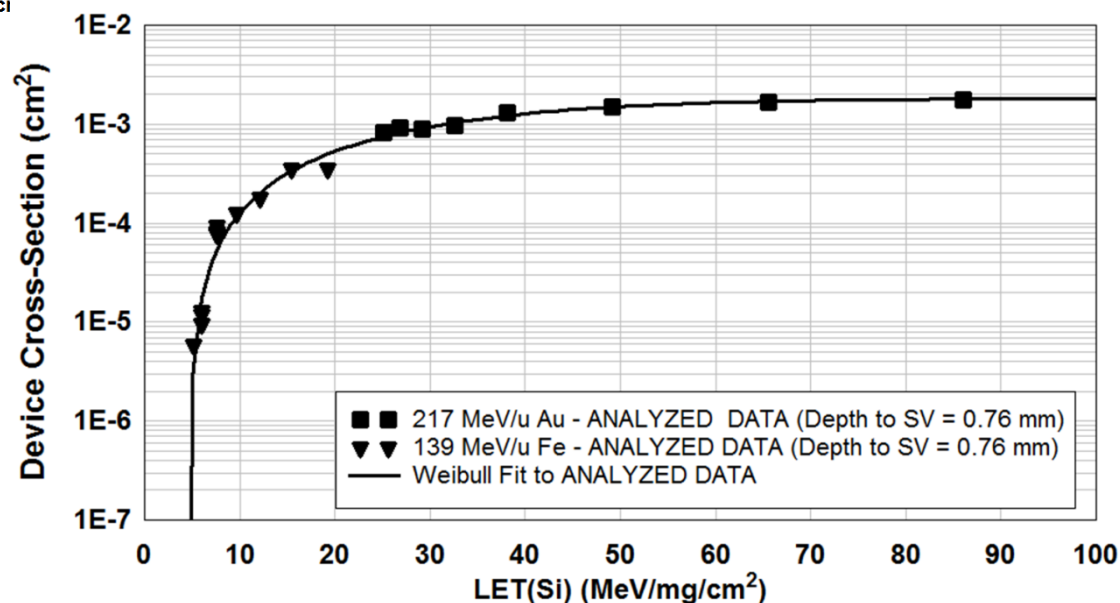
Need to know: Energy of Ions at DUT, $E_D \pm \Delta E_D$

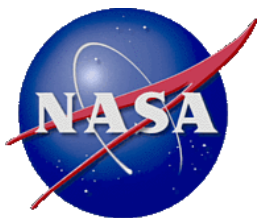


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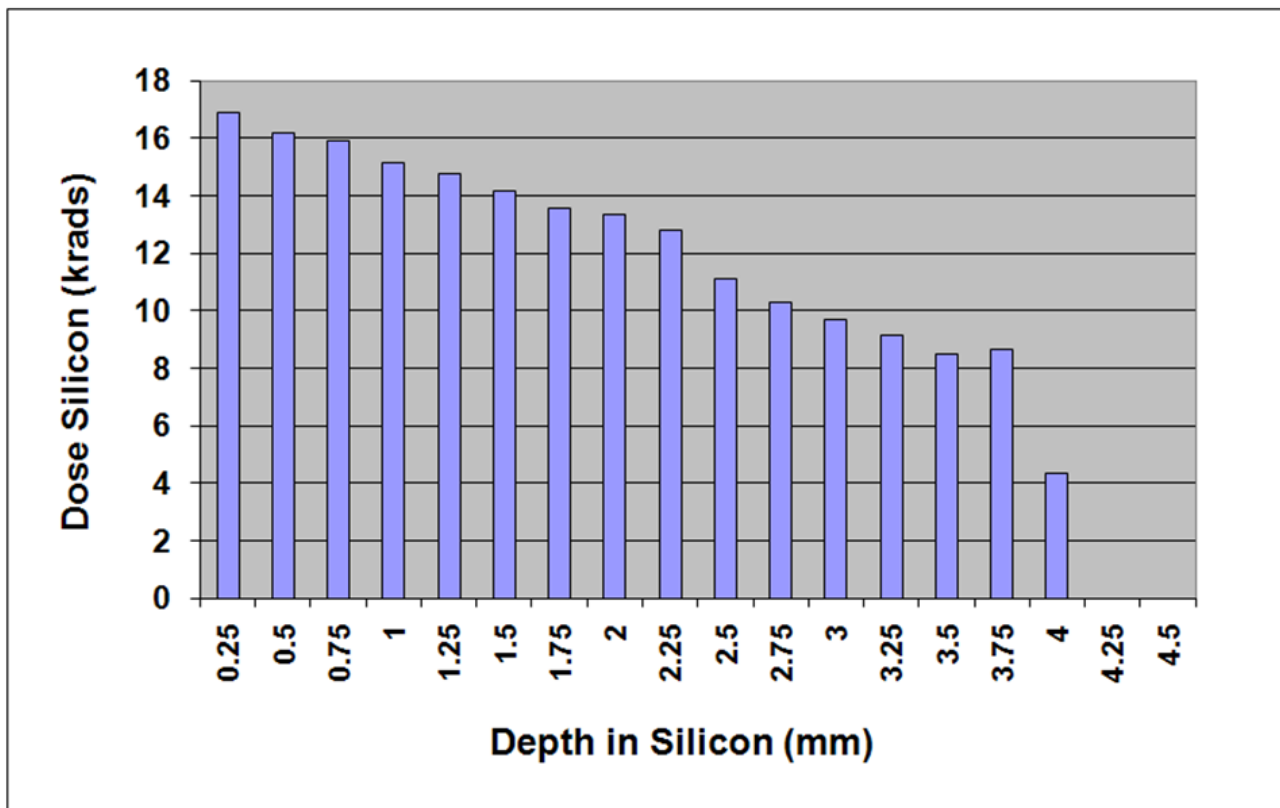


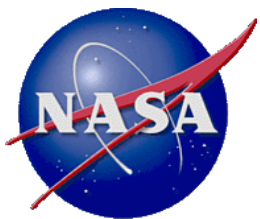
VDBP – Analyzed Data





VDBP – Total Ionizing Dose

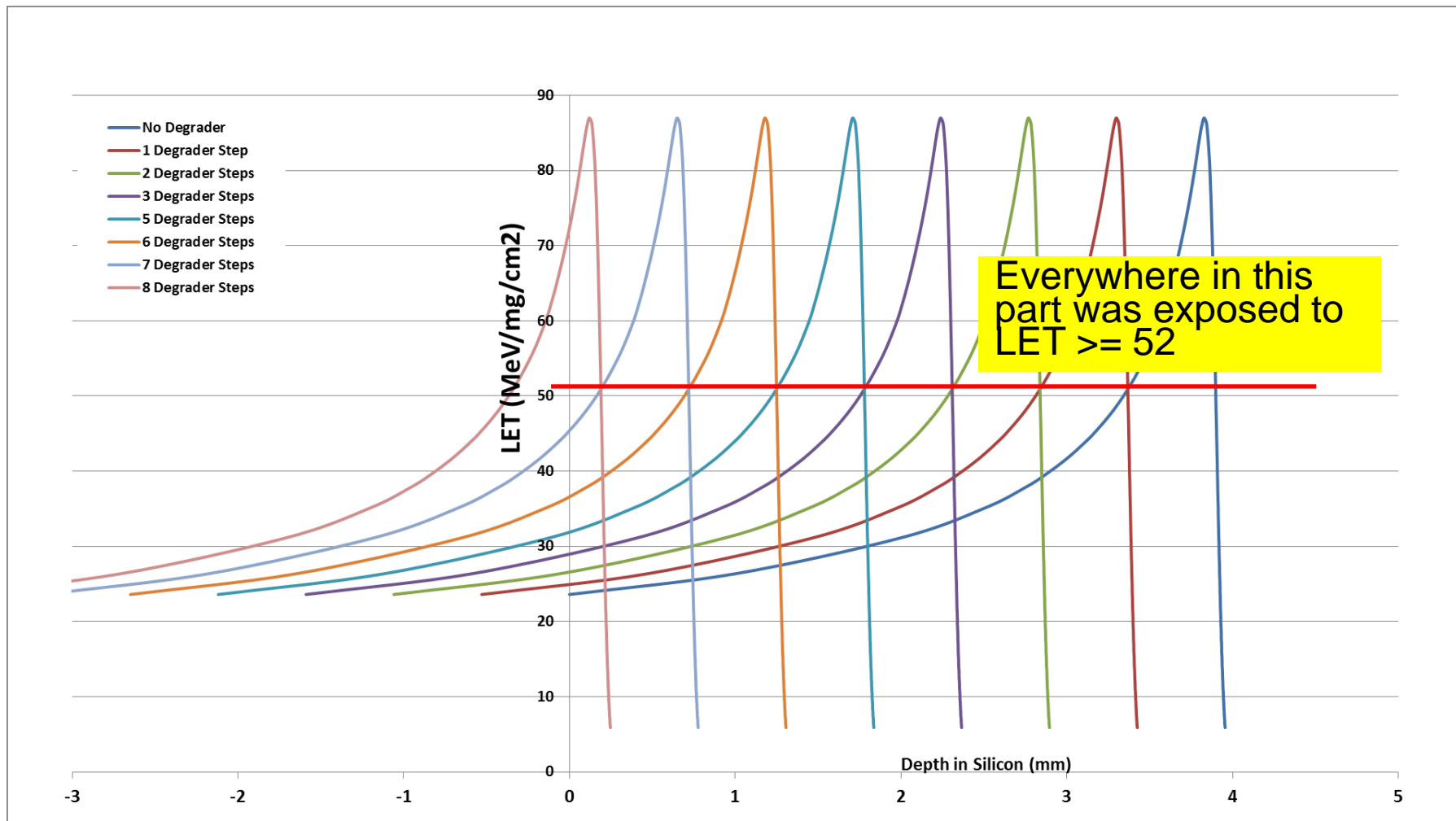




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VDBP – Quick (< 1hr) screen, i.e. Destructive Errors

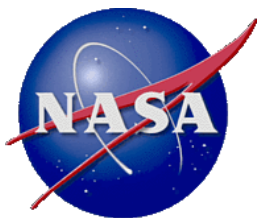




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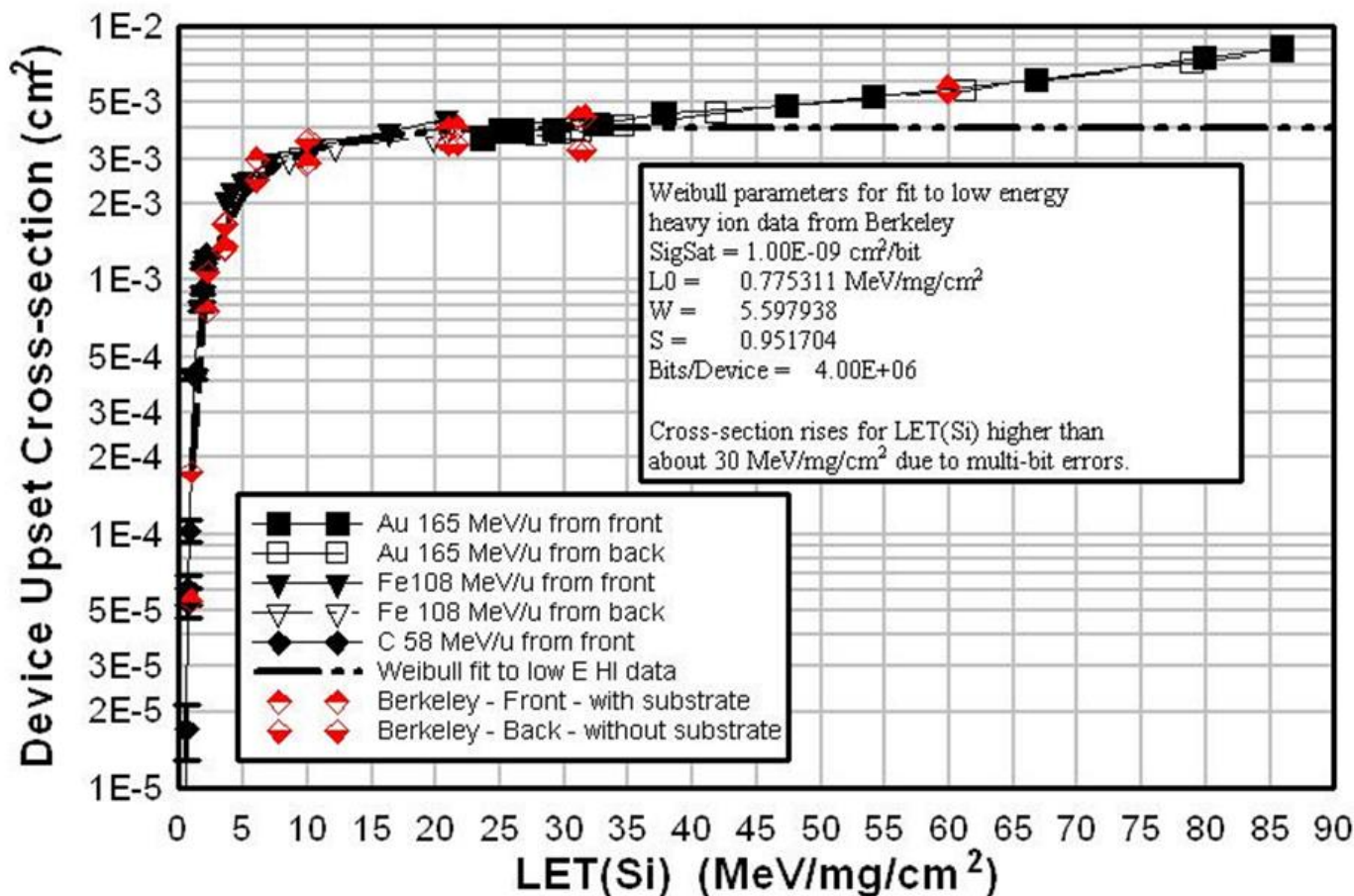
VDBP Validation/Results Examples

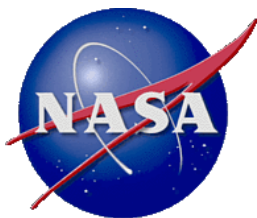


VDBP Validation (Single Event Upset)

FreeScale SRAM

High energy Heavy Ion Data - NSRL - October, 2010





Single Event Latch Up Validation

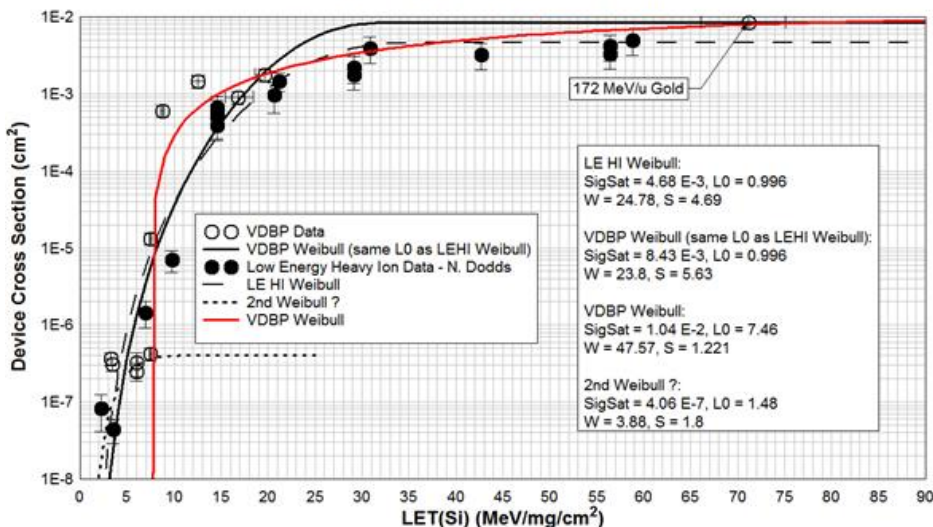


JAZZ Test Structure Latch Up Test

126.6 MeV/u Iron - Temperature 30 C

Dsv = 0.11 mm

Variable Depth Bragg Peak Method with SOBPK.for

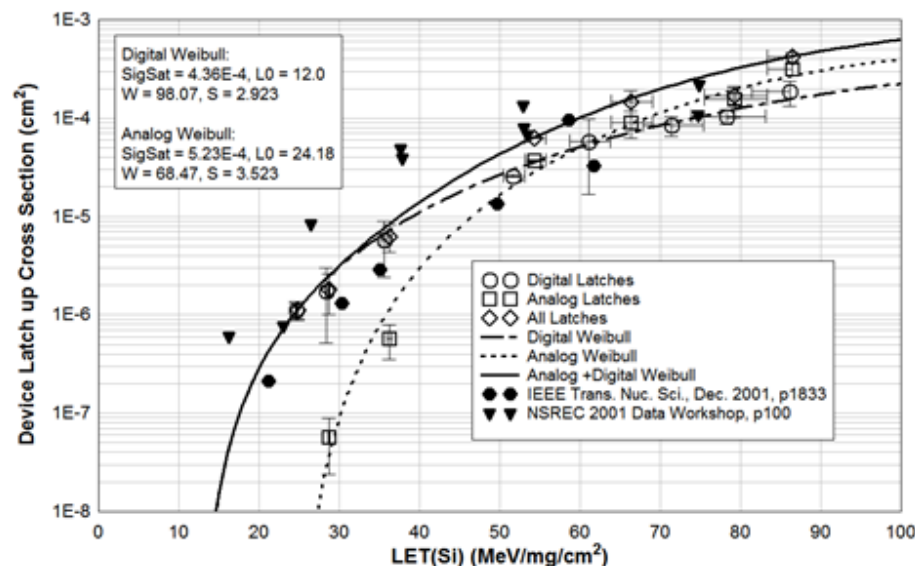


AD9240 Latch Up Test

172.4 MeV/u Gold

Dsv(Digital) = 0.552 mm, Dsv(Analog & All) = 0.618 mm

Variable Depth Bragg Peak Method with SOBPK.for



Results of the VDBP measurements of the latch up cross-sections versus LET(Si) for the Analog Devices Inc. Vertical error bars are for counting statistics only. Horizontal error bars indicate the estimated uncertainty in assignment of the LET(Si) values.



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The End – Thanks!